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Light propagation through the eye: numerical considerations and applications to presbylasik surgery analysis

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Light patterns calculation inside the eye

- Transmittance evaluation of cornea
- Transmittance evaluation of crystalline lens
- Wave propagation (angular spectrum) up to the plane of interest.
- Applications to presbylasik surgery analysis

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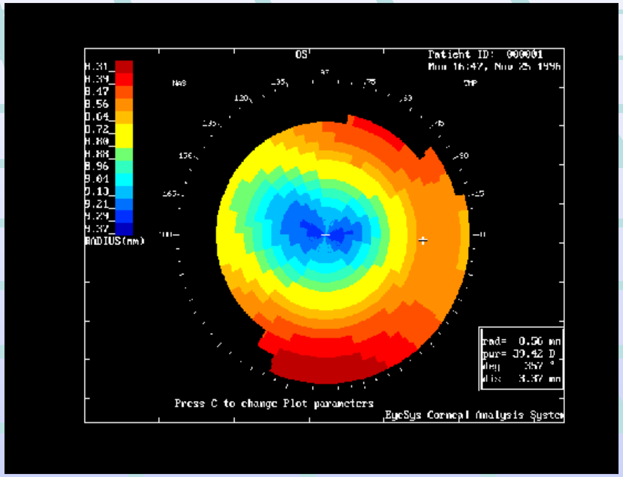
Corneal transmittance evaluation:
- Geometrical configuration

2 surfaces

1st surface: Corneal topography



2nd surface: Dubbelman 2003

$$x^2 + y^2 + (1 + Q_2)z^2 - 2R_2 z = 0 \qquad \begin{cases} R_2 = 6.6 - 0.005 \times age \\ Q_2 = -0.1 - 0.007 \times age \end{cases}$$

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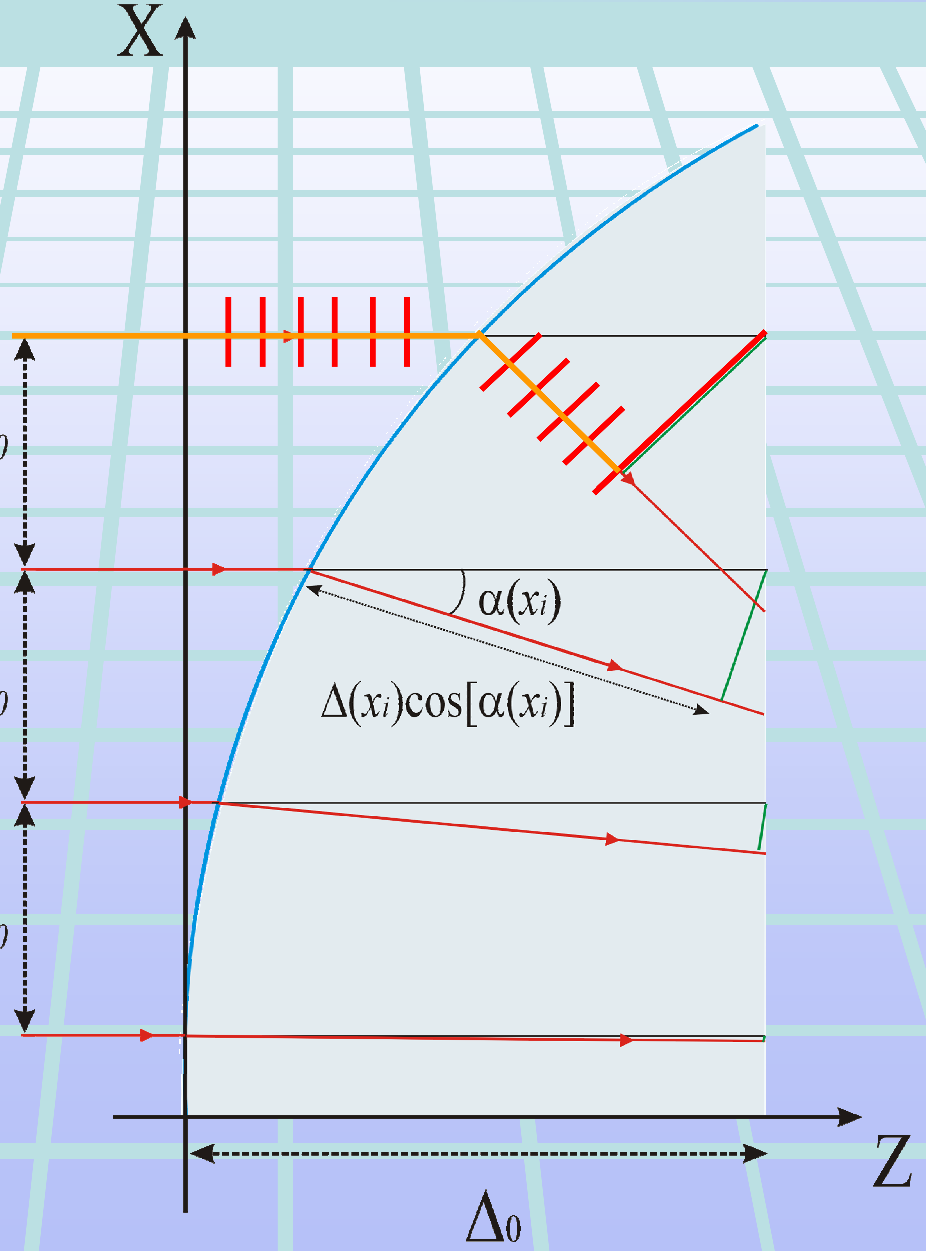
Corneal transmittance evaluation:
- Optical path length



Crystalline lens transmittance evaluation

Dubbelman 2001 (Scheimpflug photography)

$$x^2 + y^2 + (1+Q)z^2 - 2Rz = 0$$

$$R_{ant} = 12.9 - 0.057 \times age; \qquad Q_{ant} = -6.4 + 0.03 \times age$$

$$R_{post} = -6.2 + 0.012 \times age; \qquad Q_{post} = -6.0 + 0.07 \times age$$

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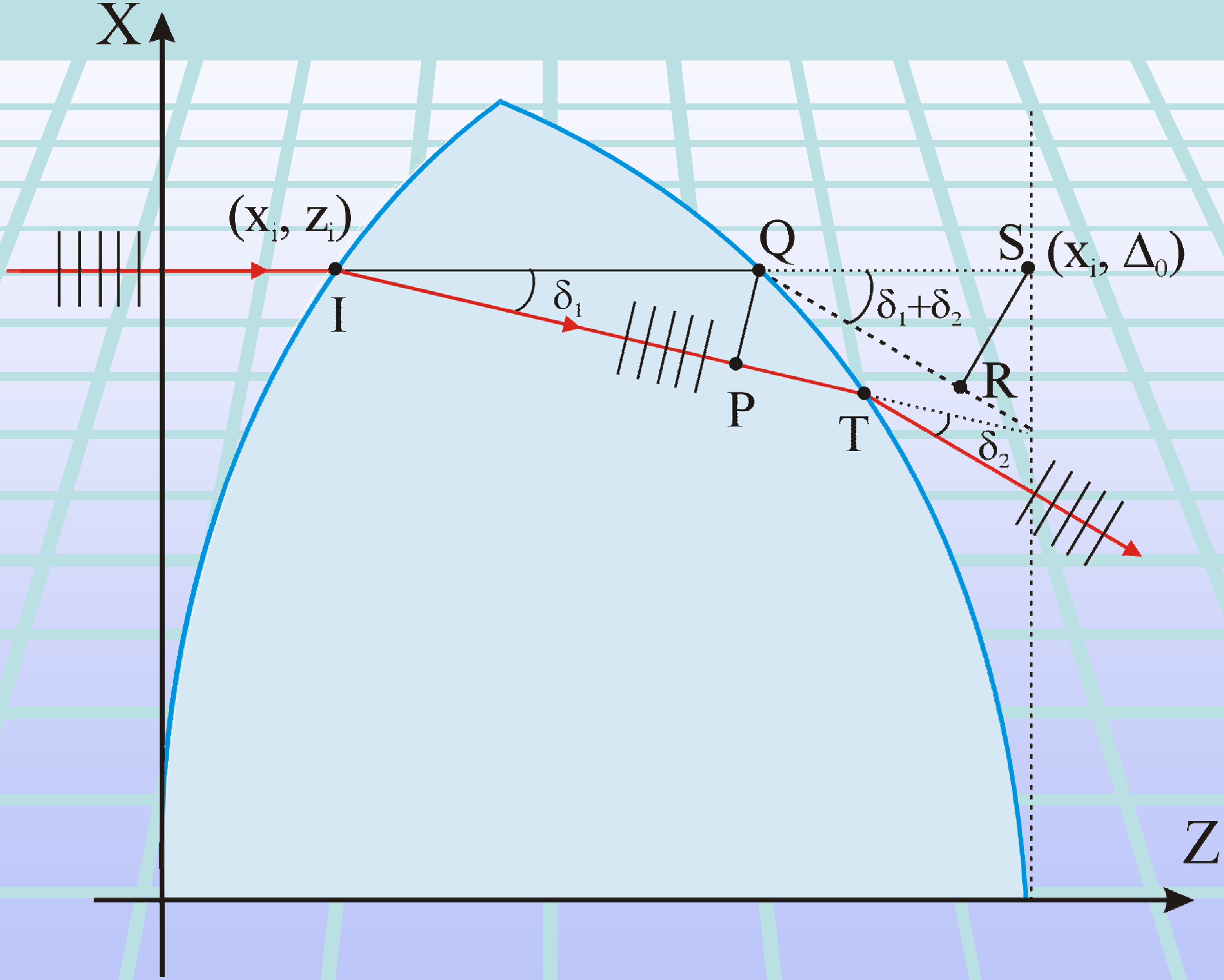
Crystalline lens transmittance evaluation



$$op_i \approx z_{1i} + n\left(z_{2i} - z_{1i}\right)\cos\delta_{1i} + \left(\Delta_0 - z_{2i}\right)\cos\left(\delta_{1i} + \delta_{2i}\right)$$

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Wave propagation

Convergent patterns calculation

$$(u_z)_\mu \propto DFT^{-1}\left\{ \begin{array}{l} \exp\left(-i\pi \dfrac{\lambda z}{(\Delta x_0)^2}\tilde{m}^2\right)\times \\ \times DFT\left[u_0\left(\dfrac{m\Delta x_0}{N}\right)\exp\left(-i\pi \dfrac{m^2(\Delta x_0)^2}{\lambda N^2}\dfrac{1}{z_c}\right)\right] \end{array}\right\}$$

Nyquist condition $\Rightarrow$ $z \le \dfrac{\Delta x_0^2}{\lambda N} \le z_c$

Total eye $\left\{ \begin{array}{l} z_c = 20\,\text{mm} \\ \lambda = 633\,\text{nm} \\ \Delta x_0 = 6.7\,\text{mm} \\ \Phi_p = \left(3/4\right)\Delta x_0 \end{array} \right\} \Rightarrow N = 3600$

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Wave propagation

Nyquist condition: $N\lambda \geq \dfrac{\Delta x_0^2}{z_c}$

Let us define $\kappa > 1$, $N' = \dfrac{N}{\kappa}$ and $\lambda' = \kappa\lambda$

$$\Delta\xi = \frac{1}{\delta x_0} \Rightarrow \Delta\xi' = \frac{1}{\delta x_0'} = \frac{\Delta\xi}{\kappa}$$

$$\left.\begin{array}{r} \Delta x_0 \Delta\xi' = N' \\ \\ \Delta\xi' \Delta x_z = N' \end{array}\right\} \Delta x_0 = \Delta x_z$$

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Wave propagation

Rectangle function

$\kappa=1$ vs. $\kappa=4$

$z_c= 20$ mm $\Delta x_0=6.7$ mm N=3600

Prop. distance (mm)	Intensity error (sd)	Phase error (sd)
18	4.47%	1.12%
19	3.61%	0.48%
20	0.52%	1.98%
21	3.98%	4.73%
22	4.70%	10.28%

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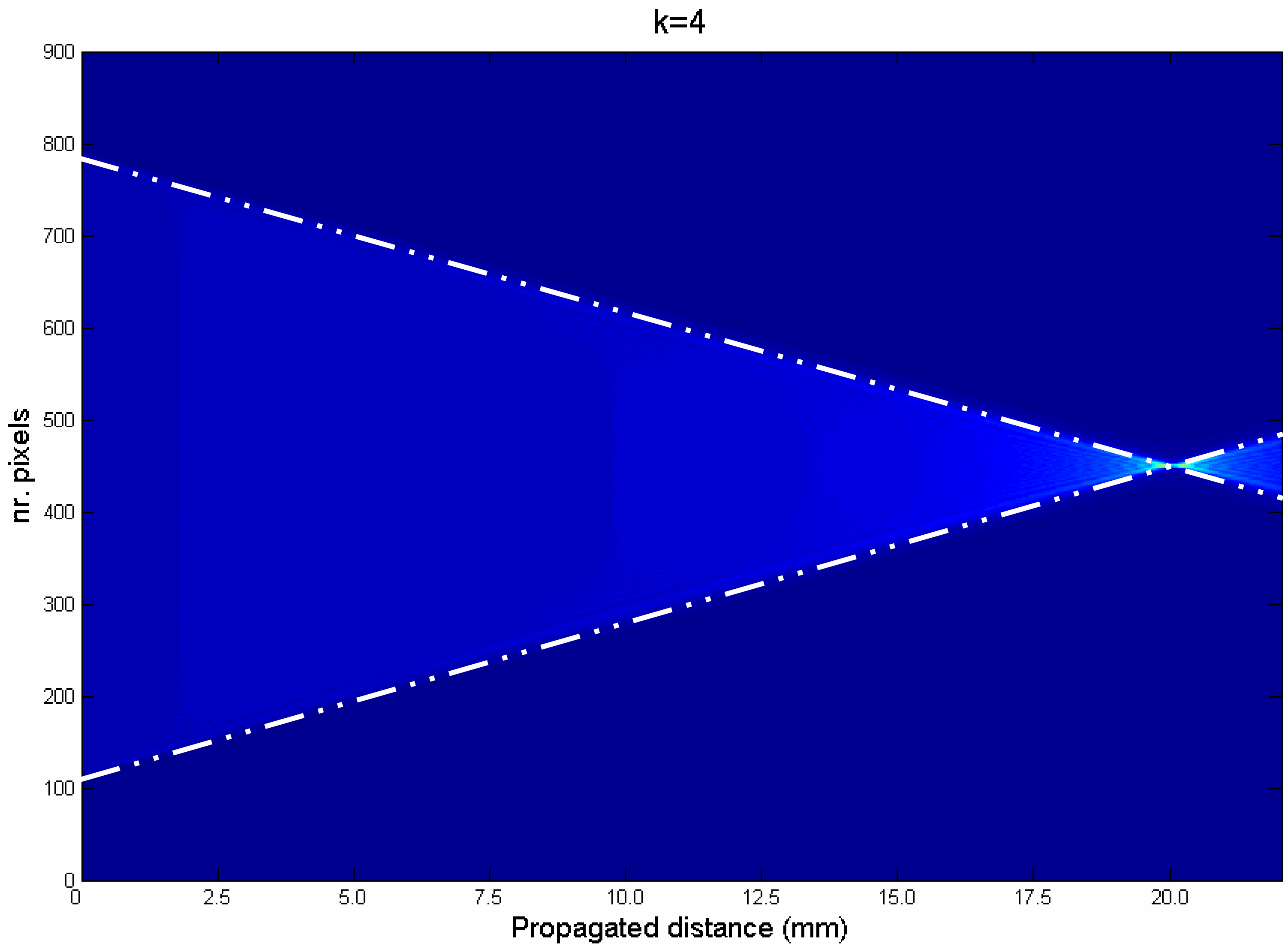
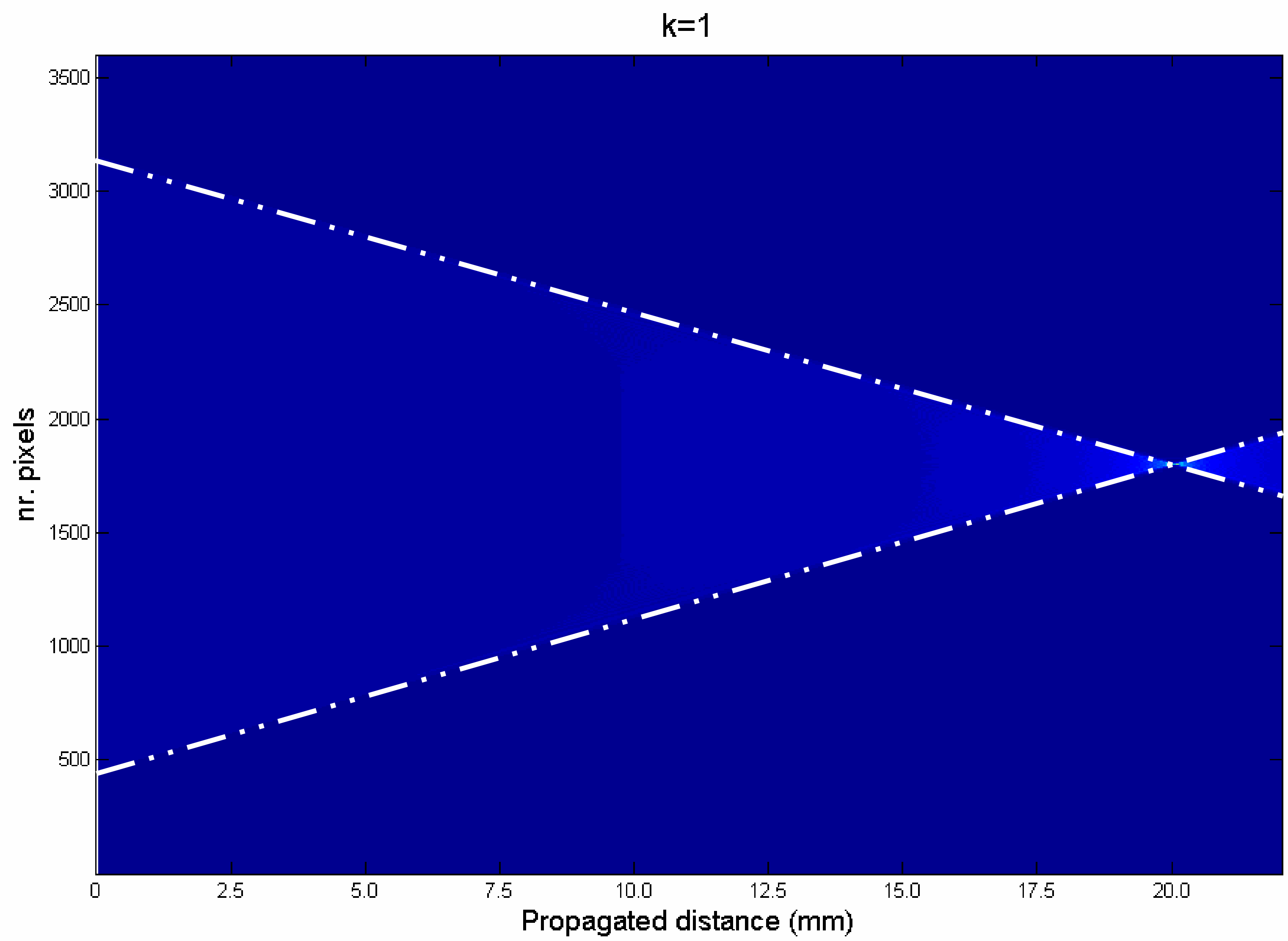
Wave propagation



Wave propagation



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Wave propagation

Total eye $\left\{\begin{array}{l} z_c = 20\,\text{mm} \\ \lambda = 633\,\text{nm} \\ \Delta x_0 = 6.7\,\text{mm} \\ \Phi_p = \left(\frac{3}{4}\right)\Delta x_0 \end{array}\right\} \Rightarrow N = 3600$

$\delta x_0 = \Delta x_0 / N \approx 3\lambda \Rightarrow \Delta\xi \approx 540\ \text{mm}^{-1} \approx 82\ c\,\text{deg}^{-1}$

Visual Acuity =1.3 $\Rightarrow$ $40\ c\,\text{deg}^{-1}$

Lossless subsampling by a factor

$$\kappa = 2$$

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Application

Optical quality of the eye after presbylasik surgery

- Correction for presbyopes with hyperopia
- Multifocal corneal ablation
- Decimal VA estimation
- Pseudo accommodation range

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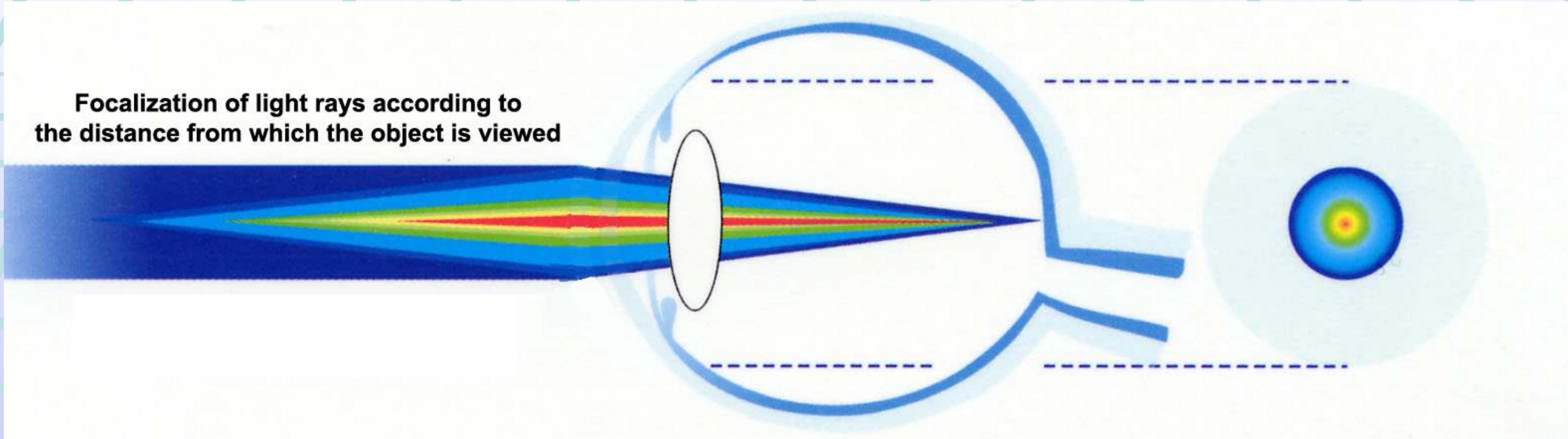
Application

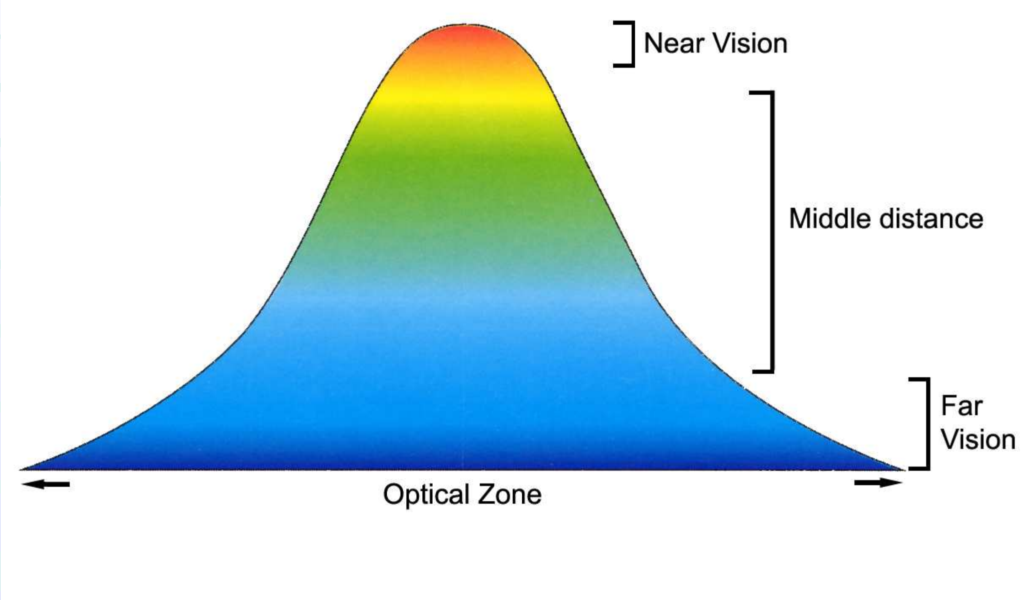
Optical quality of the eye after presbylasik surgery

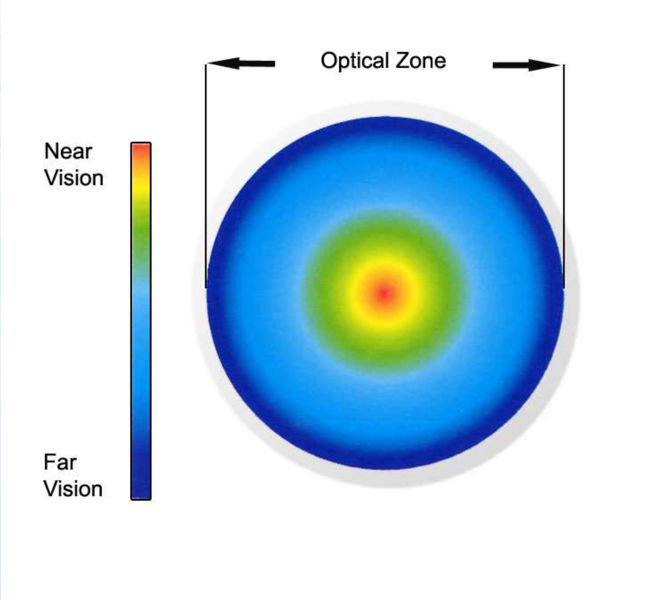


Chaubard 2003

Application

Optical quality of the eye after presbylasik surgery





Chaubard 2003

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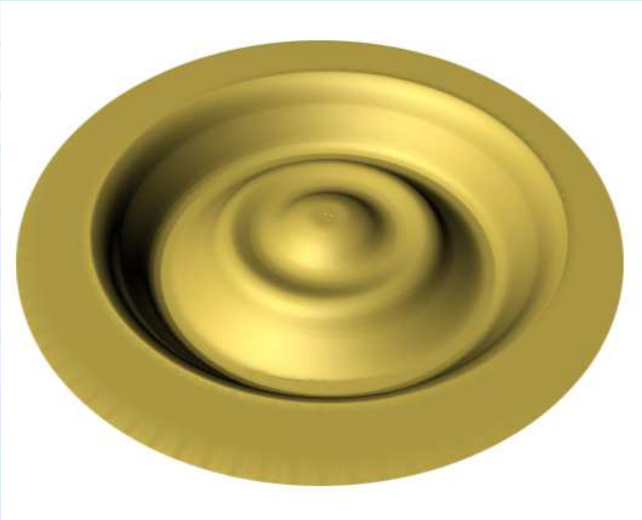
Application

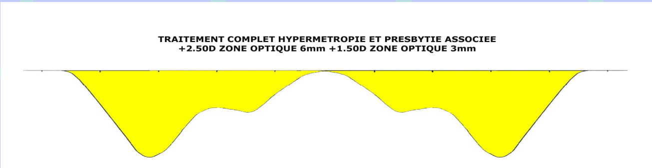
Optical quality of the eye after presbylasik surgery

Far Vision Correction

Near Vision Correction

Combined Treatment





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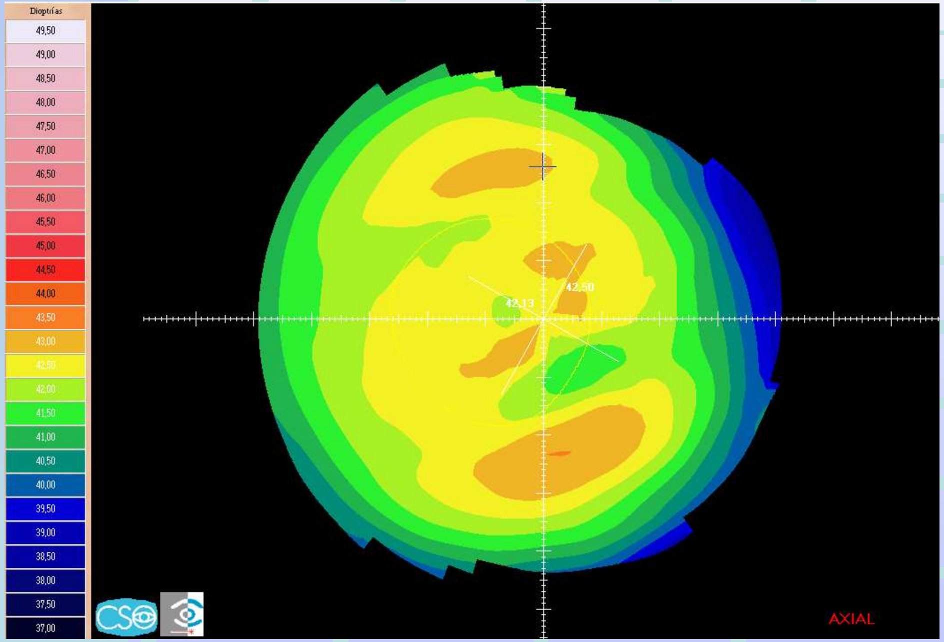
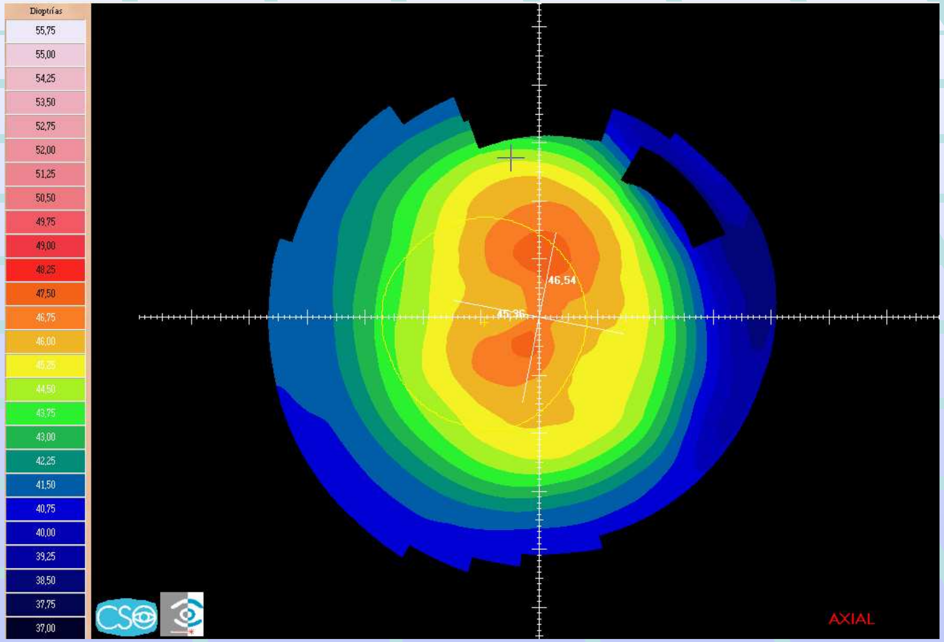
Application

Optical quality of the eye after presbylasik surgery





Central Presbylasik surgery
(H. Eye Tech. Technovision excimer laser platform)

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Subjects

8 hyperopic eyes

Mean age: **57 years**

Mean preoperative spherical equivalent refraction:

1.28 ± 0.87 D

Mean preoperative VA: **1.02 ± 0.13 (corrected)**

0.37 ± 0.15 (uncorrected)

Presbyopia: <2 D

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Clinical results

Mean postoperative spherical equivalent refraction:

-0.46 ± 0.49 D

Mean postoperative VA:

0.95 ± 0.09 (corrected)

0.72 ± 0.18 (uncorrected)

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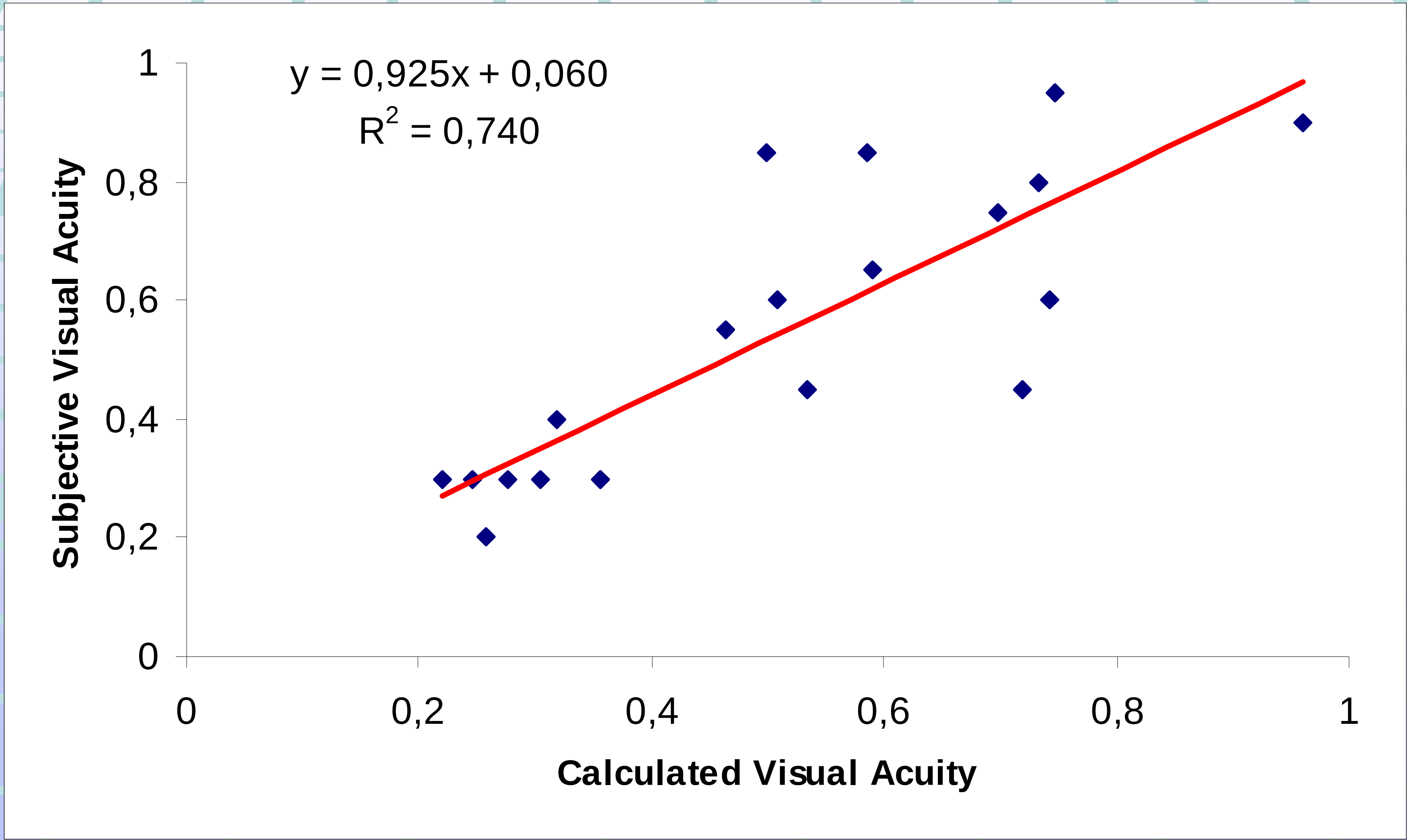
Results



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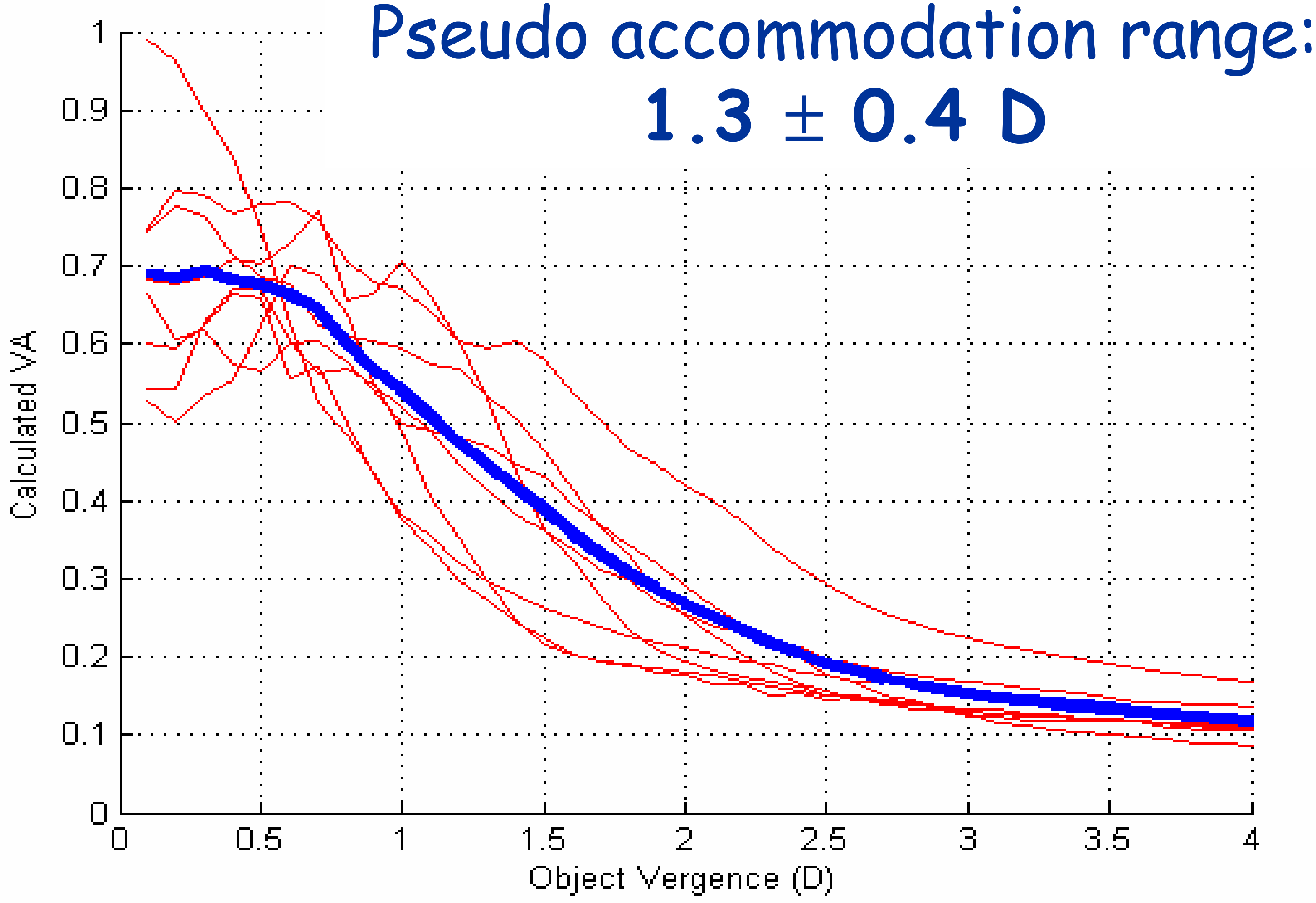
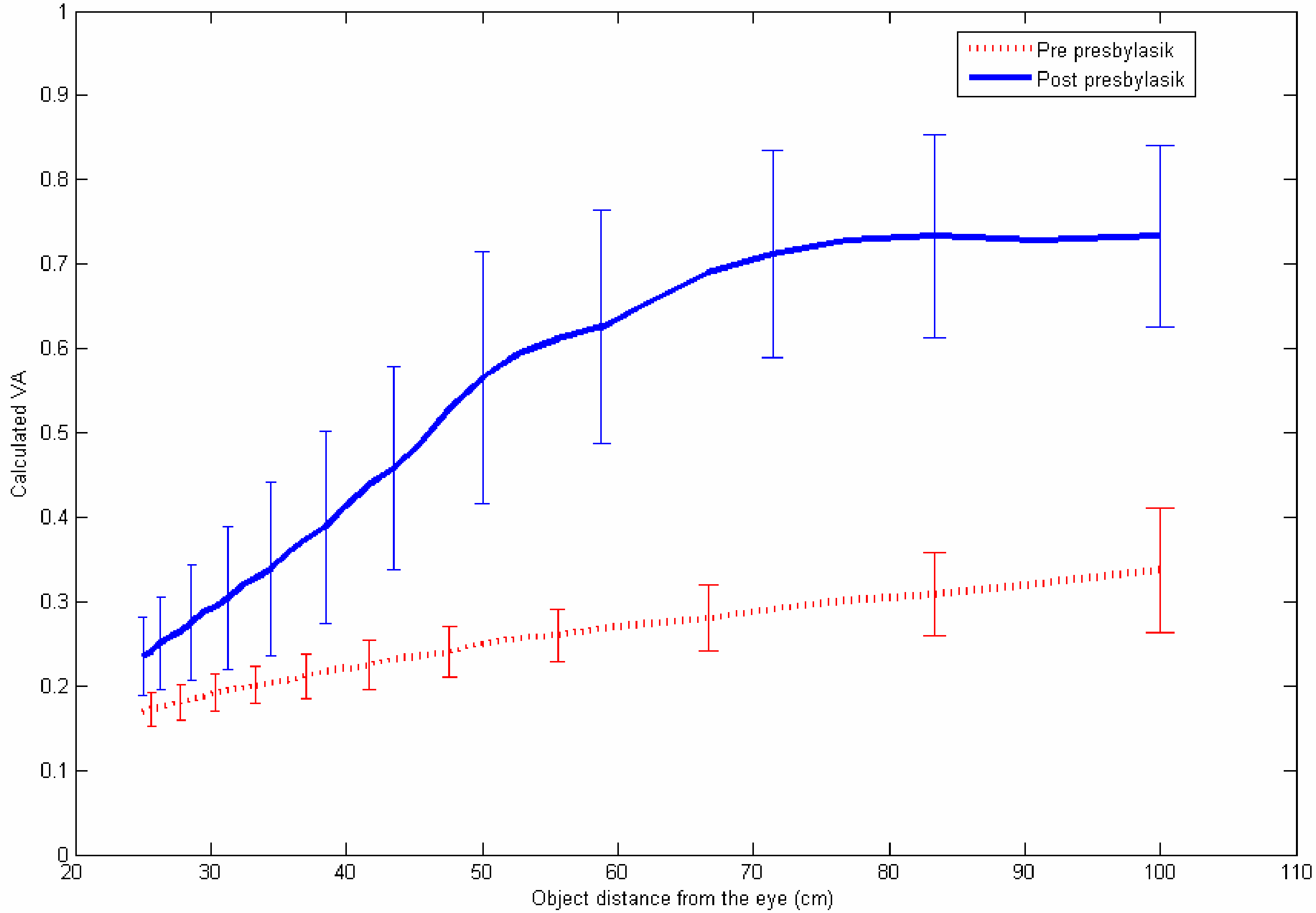
Objective results

ϕ=4 mm



Near distances

ϕ=3 mm Acc=+1 D



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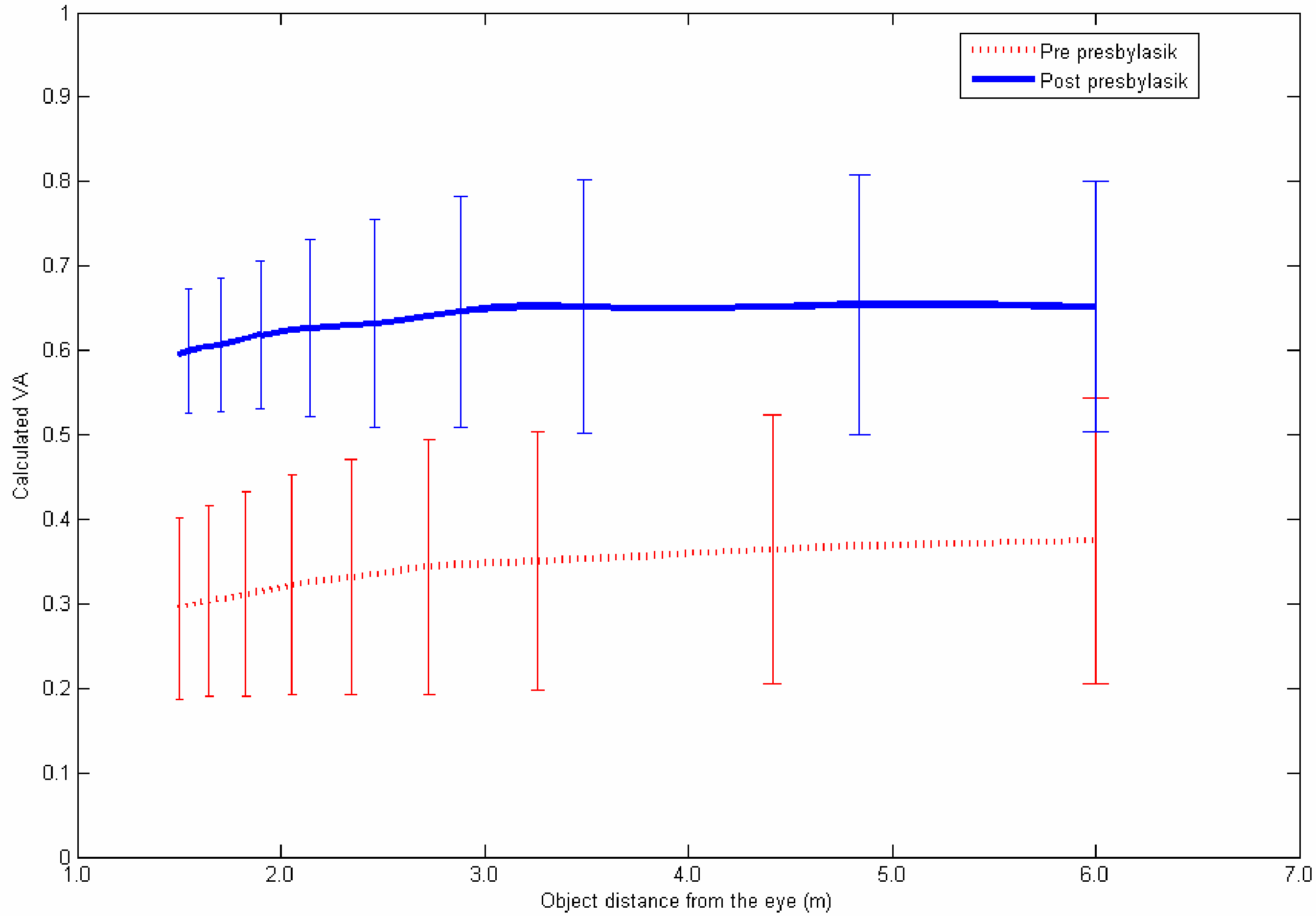
Far distances

ϕ=5 mm



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